## Art. XII.—*The Sounds of the Consonants, as Indicated by the Phonograph.*

By Alex. Sutherland, M.A.

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On its first discovery, the phonograph was hailed with much satisfaction by those who are devoted to the study of music as a physical science, but a few months of actual experience have shown that their hopes were by no means likely to be fulfilled. As a means of registering sounds the phonograph is not to be compared with methods that have long been known; the phonautograph of Leon Scott, the manometric flame of König, the graphic method of Duhamel, all give results that are more easy of interpretation than the phonograms printed by the new instrument on tin-foil. It is almost impossible to see, much less properly to estimate, the minute and delicate curves contained in the dots which make up the phonogram. A microscope gives little assistance, for when one looks down into an indentation presenting intricate surfaces of curves in three dimensions, the unaided eye can distinguish little of any importance in its appearance.

Various contrivances have already been adopted for the purpose of examining these indentations more thoroughly; one observer has made careful sections of the tin-foil, and by magnifying these to the extent of about 400 diameters has been able to verify the results already obtained by other instruments. Jenkins and Ewing in their recent articles in *Nature* described multiplying arrangement which they have used with success in order to obtain magnified tracings of the marks obtained by singing the vowels into the phonograph. In this way they have made careful analyses of the wave forms which constitute the vowel sounds ū and ō when sung in different notes. But they cannot claim to have discovered a single new fact. The truth seems to be that while the tin-foil on which the phonograms are imprinted is impressed with moderate ease, there is yet enough of mechanical resistance to destroy altogether the finer sorts of vibrations.

Now we know from Helmholtz's researches that while

the pitch and intensity of a note depend on the rapidity and amplitude of its vibrations, its richness, and indeed all that serves to give character to the note, depend on the number and kind of secondary vibrations with which the main vibration is attended. Thus if the note is attended by its octave, that is, if in addition to the vibrations which give the note itself, there are present a secondary set of vibrations of twice the rapidity, then we have a sound which the ear recognises at once as musically the same note, and yet it perceives a richness and fulness which was not present in the simple tone. If to this double set of vibrations there be added a third set, three times as rapid as the first, there is again a change in the quality of the tone; and while a musician would say that the note was the same, the ear would nevertheless declare that though the pitch and intensity were the same, the character is notwithstanding quite different.

It was from the consideration of this last element, the quality of the note, that Helmholtz was able to originate the theory now generally accepted as to the nature of the vowel sounds. Every set of vibrations given off either by the human voice or by any musical instrument tends to strengthen itself by the addition of a series of harmonics, the first being twice as rapid as itself, the next three times, the next four times, the next five times, and so on. Thus, if the sound be C we may have this note strengthened by the addition of the C above, by the G above that, by the next C, the next E, the next G again, and so on.

Now it is possible by means of resonators to strengthen any one of these secondary vibrations, and so completely alter the character of the note produced; if a person were to sing the same note through funnels of different shapes the sounds would still be recognised by the ear as the same note, but each would have its own distinctive character.

This is all that takes place when a vowel is pronounced by a human voice; a certain note is emitted by the larynx, the mouth is shaped into a resonator so as to strengthen certain of the harmonics of that note. If the mouth is partially opened, and the cavity made somewhat round by the action of the under-jaw, we have the second partial tone strengthened and made equal, or in some cases more intense than the fundamental note; the result is that the primary vibration is followed by a second equal to it, and so the phonogram gives for the long sound of ō a series of dots

arranged in pairs; in the word "mole," pronounced in a deliberate way but without dwelling unnecessarily on the syllable, there are about ninety of these pairs of vibrations to make up the vowel sound.


The long sound of *ū* or *oo* as in "roof" consists of the fundamental note strengthened by its third partial, that is if the vowel be spoken on the note C, there will be added to this a series of vibrations corresponding to the G of the octave above. The marks produced consist of a series of pear-shaped dots closely contiguous, the broad end representing the place where the fundamental is reinforced by its second harmonic, the narrow end representing the secondary smaller vibrations.

In the word "roof," pronounced with moderate rapidity, there are between forty and fifty of these impressions to represent the vowel sound.

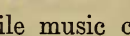
The vowel ā, as in "far," consists of the fundamental note strengthened by both the second and third partials; hence its phonograms partake of the characters both of ō and of ū. A slightly pear-shaped dot is followed after a definite interval by a much smaller dot. In the word "far" it takes from 150 to 170 of these pairs to give the vowel sounds.

The sound "awe" has altogether four partials, the fundamental tone together with its three first harmonics; its phonogram seems to consist of two pear-shaped dots of which the second is slightly less than the first.

The remaining vowels I have made no effort to analyse, but their phonograms, so far as I can make out, are—

ŏ 

ē 

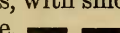
ŭ 

It is plain, then, that while music can be produced by simply reproducing the fundamental vibration we can hope

to reproduce a vowel sound only by adding to that fundamental its proper harmonic. Now, for the first and second harmonics the phonograph does this with sufficient distinctness, hence we get the vowels ō and ū and ā well enunciated; but when we come to produce the vowels ē, āū, ŭ, &c., the results are vague, for the vibrations are too feeble to register themselves properly on the tin-foil, and so, while the fundamental note is loudly sounded, the vowel is almost beyond recognition.

The ear has the power of analysing all these vibrations, but when the sound is drawn by any of the graphic methods the eye does not recognise each of them as a distinct vibration, but sees a single set of vibrations, whose lines are broken and varied by the super-position of the smaller sets. In the phonograms, as seen on the tin-foil, we see the fundamental vibrations marked as a row of prominent dots; the harmonics appear either as smaller dots between, or as variations in the thickness and depth of the main juncture. This is the origin of the pear-shaped dots which recur so often, and also of the dashes which seem as though drawn out in some places and thickened in others. Among the consonants we have to distinguish two very different classes. The sibilants and liquids have wave-forms of their own which are no less constant and definite than those of the vowels; but the remainder which form the real consonants have no wave vibrations peculiar to themselves; perhaps it might be more correct to say that they have no vibrations whatever, but exist only as modification of the vowel sounds.

First, as to the liquids.—Of all the letters there is none that gives so marked a phonogram as R. This consists of groups of dots varying from four to ten, according to the amount of roughness put in the letter, and these groups are separated by intervals equal to about four of their wave lengths. The dots are similar in shape to those of the vowel ŭ, and so we reach the conclusion that the liquid *r* is nothing more or less than the vowel ū interrupted twenty or thirty times in a second.

The letter *l* has a simple sound; its phonogram consists of a series of bars, with smooth surfaces, that is, there are no harmonics visible,  ; the curve dips into the tin foil, and then rises by an unbroken sweep. This is what we should expect; for in pronouncing this sound the mouth is closed by the tongue being placed close against the palate,

while the breath issues through the narrow passage then left. The larynx produces its note, consisting of the fundamental vibrations with its harmonics, but there is now no resonating cavity to strengthen any one of these harmonics, and so the letter *l* passes forth as an almost purely musical note; none of the harmonics being strengthened, they are unable to make any impression on the tin-foil, and so we have nothing more than a series of simple dashes.

M seems likewise to consist of a series of dashes, but at the end of every dash there occurs a small dot indicating, I suppose, the existence of some harmonic. The sound of this letter is made by allowing the breath to pass through the nose, and the nasal cavity must in some manner act as a resonator, giving prominence to certain of the partials, but this effect is weak in comparison with the similar action by which the mouth produces the vowel sounds. At the same time the nasal cavities cannot have all to do in the production of the sound of *m*, for if while sounding this letter we raise the tongue and so contract the cavity of the mouth, even though the latter is still kept shut, we change from the sound of *m* to that of *n*, in which the long dash is divided into a shorter dash, followed by a dot, so that the phonogram of *n* is a short dash with two dots.

The phonograph is of little use in the determination of wave-forms for sibilants. It is difficult to obtain records of these sounds, and their excessive minuteness makes it difficult to decide as to their shape. They seem, however, to consist of an excessively numerous series of small dots.

The remaining consonants are all formed in the same way, that is by either checking or letting go the breath; at the beginning of a syllable, we suddenly permit the sound to escape, at the end we suddenly stop it, and the ear recognises these sudden changes as consonants. The change may take place in three ways, either sharply and instantaneously, in which case we have the hard consonants p, t, k, or rather more gradually, which gives the softer sounds of b, d, g, or it may take place by stopping or commencing the sound without at the same time stopping or commencing the breathing. If we stop a sound at the end of a syllable, but allow the breath still to pass out, we have the sounds of f, v, th, or *ch*. The phonograms placed on the table show the differences between these three classes of consonants. With the explosive consonants p, t, k, the vowel sounds commence sharply; with the soft consonants

b, d, g, there is a gradual swell in the intensity of the dots, showing that the vowel sound was at first permitted to escape by degrees. With the aspirates f, v, th, and *ch*, a series of indeterminate marks either precedes or follows the vowel sound, showing that the breath was escaping before or after the vowel had sounded.

Now, the difference between the corresponding consonants in these three classes is much more difficult to make out. Why, we may ask, should the sudden stoppage of a sound by the lips be recognised as the letter *p*, and the sudden stoppage of the same sound by the teeth and tongue be recognised as the letter *t*, or if the tongue and palate be employed to do exactly the same thing why should we recognise the resulting consonant as *k*?

An examination of the phonograms gives some clue to this distinction. It will be found that on pronouncing a syllable beginning with *p* such as "pa" before the vowel sound has properly begun, there will be found a few marks which do not really belong to that vowel but have more affinity to the vowel ŭ; the explanation is that if the lips are closed, and we open them to emit the full sound ā, we do not at once reach the necessary resonating cavity, we have to pass through the intermediate stages. Now these intermediate stages are the resonating cavities which give the various sounds of ŭ, and though these are very few in comparison with the subsequent vowel vibrations they are sufficient to be recognised by the ear, and so we can tell at once that it must have been the lips which permitted the sudden passage of the sound.

When the consonant is produced by the tongue and teeth, as in the letter *t*, before the vowel commences we have the marks corresponding to ĕ short; and when the consonant is k, the vowel is preceded by marks corresponding first to the long ē, and then to ā, as in "may."

Hence the formation of all the consonants. They are either hard, soft, or aspirated; and the ear judges as to whether they are formed by the lips, teeth, or palate, by observing the vowels through which the sound glides before dwelling on the main vowels.

Thus we find that all sounds, to which the human voice gives rise, consist of vibrations of fixed periods, with their harmonics; the presence of these harmonics determines the nature of the vowel, and moreover enables us to decide by the ear as to which of the consonants has been uttered.